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ORIGINAL ARTICLE

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An operational heat/health warning system in shanghai

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Abstract Previous research has noted that high surface temperatures within certain "offensive" air masses can lead to increased mortality. This study assesses the relationship between daily mortality rates and weather within the city of Shanghai, China, while introducing an operational heat/health warning system for the city. Using numerous meteorological observations, the spatial synoptic classification has been used to classify each summer day from 1989 to 1998 into one of eight air mass types for Shanghai. Through the comparative analysis of the daily air mass type and the corresponding Shanghai mortality rate, "moist tropical plus" (MT+), an extremely hot and humid air mass, was identified as an offensive air mass with the highest rates of mortality. Using stepwise regression, an algorithm was produced to help predict the number of excess deaths that will occur with each occurence of the MT+ airmass. The heat/health warning system was run experimentally in the summer of 2001 and illustrated that the use of a warning system can alert the city's residents of potentially offensive weather situations that can lead to a deterioration in human health.

Keywords Heat wave · Watch and warning system · Spatial synoptic classification · Health

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Introduction

In recent years, the impact of weather on human health has become an issue of increased significance, especially considering the potential impacts of global warming and an increased urban heat island effect due to urbanization. In 1995, the Intergovernmental Panel on Climate Change (IPCC 1995) reported that climate change is likely to have a wide range of adverse impacts on human health with a significant loss of life. There is little doubt that heat can aggravate existing medical problems, particularly with the elderly, the young, and the ill (Kalkstein and Greene 1997; Smoyer 1998; Nakai et al. 1999). With the recognition that heat is the greatest weather-related killer in many areas of the world, there has been a growing impetus to develop warning systems to predict when heat waves will occur and when human health might be adversely affected. This has led to an important collaboration between international organizations to construct heat/health watch/warning systems for cities around the world. Several international agencies including the World Meteorological Organization, the World Health Organization, and the United Nations Environmental Programme have decided to promote several "Showcase Projects" dealing with the impact of extreme heat on human health. The goal is to develop a coherent set of warning systems, to improve mitigation measures, and ultimately to save lives (Kalkstein 1998).

Surprisingly, relatively few studies assessing the impact of heat on human health have been conducted in China, a country prone to severe heat waves (He et al. 1990; Sun et al. 1994; Yang et al. 2000). Furthermore, many of China's major cities possess climates very similar to those of other heat-prone metropolitan areas around the world. As a result of its potentially dangerous climate, along with high-quality mortality and meteorological data, Shanghai was selected as the second city in the Showcase Project.

Currently the Shanghai Meteorological Bureau issues excessive-heat warnings on days in which the maximum temperature exceeds 35 °C. However, the Showcase

Project, which utilizes an air mass approach, takes into account numerous weather variables such as dew point, cloud cover, temperature, and other factors that have been shown to negatively affect human health. Furthermore, the air-mass-based watch/warning system identifies specific air mass types that have been shown to increase mortality levels in Shanghai. Thus, rather than using an arbitrary threshold of 35 °C, the new system is based upon actual human responses to climate. This new warning system will allow city health departments to alert the public more effectively to offensive days when dangerous weather is predicted, thus saving more lives.

Materials and methods

Study area

The study was carried out in the city of Shanghai, China, with a population listed as slightly over 13 million in 1998. Shanghai is situated on the shores of the East China Sea and has a subtropical climate with cold, dry winters and wet, hot summers. Unlike purely tropical regions that remain warm all year round, cities that exhibit large seasonal temperature ranges, such as Shanghai, have been found to be prone to heat-related mortality since their populations are often not acclimatized to the extreme temperatures that set in throughout the spring and summer.

Data

Meteorological data were obtained from the Shanghai Meteorological Bureau. Six variables were included: surface air temperature, dew point temperature, total cloud cover, sea level pressure, and wind speed and direction. These elements are measured four times daily (0200, 0800, 1400, 2000 hours LST), and the corresponding 24 variables (6 weather observations recorded 4 times daily) represent the basis for air mass categorization. The analysis was further restricted to summer periods (15 May to 30 September). The average minimum and maximum apparent temperatures (T_{av}) were derived as a function of temperature and humidity as follows (Steadman 1979; Kalkstein 1991):

$$T_{av} = -2.653 + (0.994T_a) + (0.0153T_d^2)$$

Where T_a is air temperature and T_d is dew point temperature.

Another variable, cold degree hours (CDH), was also used to evaluate the impact of heat on mortality. CDH is calculated as follows:

$$CDH = (T_{0200} - 20) + (T_{0800} - 20) + (T_{1400} - 20) + (T_{2000} - 20)$$

Where T_{0200}, T_{0800}, T_{1400}, T_{2000} are temperatures at 0200, 0800, 1400, 2000 hours, respectively (Kalkstein 1991).

Daily deaths in Shanghai from 1 January 1989 to 31 December 1998 were obtained from the Shanghai Municipal Center for Disease Control and Prevention, and comprised the total daily mortality, deaths of the elderly (over 65 years), death rates of those aged 65 years and under, and daily mortality broken down by gender. All mortality data were adjusted to account for changes in the total population of Shanghai during the period of record. A direct standardization procedure was used, and a mortality trend line constructed, based on the mean daily mortality for each year of record. Mortality is expressed as a deviation around this inter-annual trend line:

$$M_s = M_o - (5.4411(Y - 1988) + 191.89)$$

Where M_s is the standardized mortality, M_o is the actual mortality and Y is the year.

Methods

An automated air-mass-based classification technique, the spatial synoptic classification developed at the University of Delaware (Kalkstein 1996a, b), has been used in this study to analyze more effectively the impact heat has on humans. It accounts for numerous meteorological parameters as well as their variation throughout the day and categorizes each day into one of the following eight air mass types:

- Dry polar (DP); very cold and very dry
- Dry moderate (DM); mild and dry
- Dry tropical (DT); very hot and very dry
- Moist polar (MP); cold, cloudy, rainy
- Moist moderate (MM); overrunning, cool, drizzle, foggy
- Moist tropical (MT); hot, very humid
- Moist tropical plus (MT+); the most oppressive subset of MT with very hot and humid air
- Transition (TR); a change from one air mass to the next, e.g. frontal passage.

Once each day has been classified into one of the eight air mass types, it is possible to determine which air masses are associated with elevated mortality levels. After these "offensive" air masses have been identified, a stepwise regression is run to examine what variables within the offensive air masses elevate daily mortality. For example, the time of year, consecutive days of the offensive air mass, and numerous meteorological observations were all examined. The final result is an algorithm used to estimate the number of excess deaths, and this serves as the basis for establishing the heat/health warning system.

Result

Mortality character

A scatter plot of daily mortality and temperature in Shanghai during the decade 1989–1998 shows (in Fig. 1) a seasonal pattern with the highest rates of mortality occurring in the winter (308 mean total daily deaths; range = 107–460) and minimum values during summertime (222 mean total daily deaths; range = 132–752). A total of 922,550 deaths occurred during the study period; 684,329 (74%) of those dying were 65 year of age or older. An average of 187 daily deaths of people aged 65+ years was observed. The variation in mortality during summertime is shown in Fig. 2 where death counts are

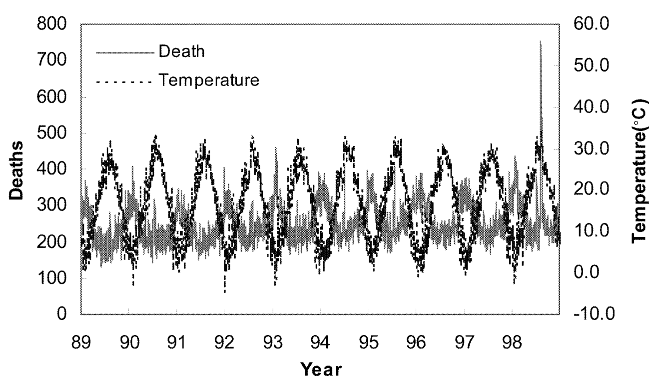

Fig. 1 Daily average temperatures and total mortality rates in Shanghai, 1 January 1989–31 December 1998

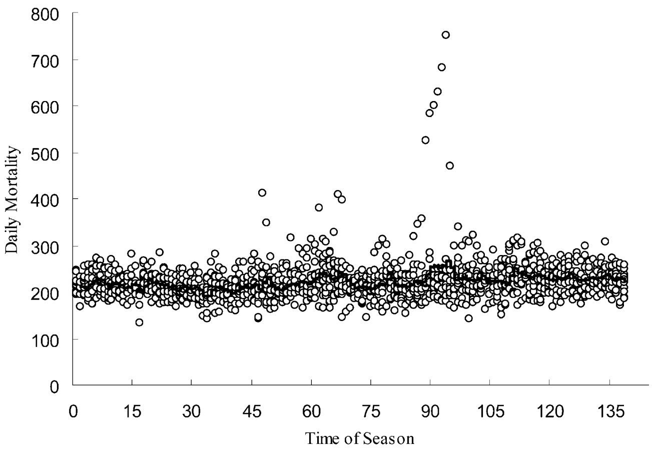

Fig. 2 Daily mortality in summertime, Shanghai, 1989–1998

Table 1 More than 3 days of heat wave (daily maximum temperature above 35 °C) in Shanghai (15 May–30 September 1989–1998)

Year	Heat wave period	Number of days	Maximum temperature (°C)
1989	11–13 August	3	36.5
1990	5–8 July	4	36.8
	13–19 July	7	36.3
1992	15–19 July	5	35.9
	27 July–1 August	6	38.2
1993	9–16 July	7	37.5
1994	29 June–6 July	6	37.9
	13–16 July	4	36.9
	22–28 July	6	35.8
1995	14–21 July	8	38.5
	5–7 August	3	36.4
	11–13 August	3	38.1
	1–9 Spetember	9	38.2
1996	18–21 July	4	37.1
1998	30 June–3 July	4	37.1
	11–21 July	11	38.6
	7–17 August	11	39.4

plotted against the time of season. Although the mean daily mortality is generally lower in summer, distinct increases occurred in both July and August. In fact, on several days the death rates were triple the summer average, especially in 1998.

For this study, a heat wave is defined as a period of at least 3 days with a maximum temperature of at least 35 °C. According to this definition, there were 17 heat waves in the past 10 years (Table 1), the most severe ones occurring in 1998 in which there were 3 distinct heat waves, 2 lasting over 10 days. In addition to a 35 °C maximum temperature threshold, it seems that apparent temperatures over 40 °C have a similar effect, often elevating death levels (Fig. 3).

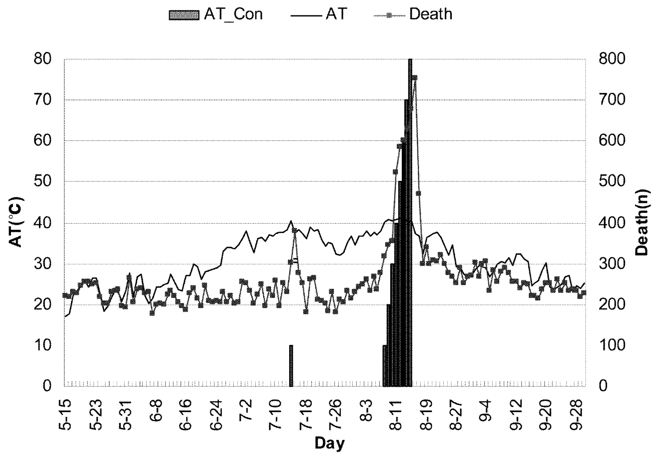

Fig. 3 Apparent temperature (AT), consecutive days of AT above 40 °C (AT_Con) and death in the summer of 1998

Air masses and mortality

Table 2 lists the frequency of each air mass throughout the summer months. As expected, the warmer air masses such as MM, MT, MT+, and DM are more prevalent in the summer while cooler ones tend to occur more frequently in the winter. Furthermore, Table 2 illustrates the average meteorological characteristics for each air mass during the summer months. It is important to note that MT+ contains both the highest average temperatures and dew points.

Average mortality levels were examined within each air mass to determine which air mass or air masses have a negative impact on human health (Table 3). Furthermore, daily mortality was sorted from highest to lowest during the period of record to determine whether certain air masses were recorded more often on the days with the highest summer mortality. For many cities, it is apparent that one or two hot air masses are linked to a much higher mean mortality than the others, and these “offensive” air masses contain an inordinately high percentage of days with the greatest mortality totals (Kalkstein 1991). For Shanghai, an offensive air mass is identified as MT+ (Tables 3, 4). From Table 2 and Table 3, it is clear that MT+ is the hottest air mass in Shanghai and is associated with a mean mortality that is significantly higher than those relating to the other seven air masses, with an additional 35–63 deaths/day on average. Considering that Shanghai averages about 222 deaths/day, this is a substantial 16%–28% daily mortality increase. MT+ comprises approximately 12.5% of all summer days in Shanghai and contains the highest temperatures and dew point temperatures of any air mass, always involving southwest winds and often containing some mid-level cloud cover. We can also see that the average daily mortality in the over-65 age group was elevated within MT+. This suggests that the elderly are particularly vulnerable when offensive air masses are in place and are most likely to suffer from heat stress. Finally it is

Table 2 Mean frequency and character of the air mass in Shanghai in summertime. *DP* Dry polar, *DM* dry moderate, *DT* dry tropical, *MM* moist moderate, *MP* moist polar, *MT* moist tropical, *MT+* moist tropical plus, *TR* transition

Air mass	Frequency (%)	0200 hours			1400 hours		
		Temperature (°C)	Dew point (°C)	Cloud cover	Temperature (°C)	Dew point (°C)	Cloud cover
DM	11.0	19.4	15.1	4.5	25.4	13.6	5.0
DP	0.1	17.4	10.9	5.0	20.1	13.7	5.0
DT	0.6	20.4	12.3	1.8	30.3	11.0	3.1
MM	36.5	22.3	20.3	9.2	24.6	20.6	9.0
MP	0.4	16.2	12.8	9.6	18.3	13.6	9.1
MT	34.7	25.3	23.1	5.8	29.9	23.3	6.1
MT+	12.5	28.1	25.0	5.3	33.7	25.2	6.1
TR	4.1	23.6	21.3	8.2	25.7	19.8	8.3

Table 3 Air mass and mortality

Deaths	DM	DP	DT	MM	MP	MT	TR	MT+
Those over 65	160	134	170	147	148	160	156	198
Those under 65	61	69	61	60	66	62	62	68
Male	117	91	117	110	112	117	115	134
Female	104	112	114	97	102	105	103	132
Total	221	203	231	208	214	222	218	266
SD	25	24	24	23	30	25	27	79
Number of days	153	2	8	508	6	482	57	174
Frequency (%)	11.0	0.1	0.6	36.5	0.4	34.7	4.1	12.5

Table 4 Tally of the frequency with which each type of air mass was present on high-mortality days, Shanghai (15 May–30 September 1989–1998). σ Standard deviation

Excess deaths	Exceeding average by:	Frequency of occurence of each air moss type							
		DM	DP	DT	MM	MP	MT	MT+	TR
>79	>2σ						1 4%	26 96%	
59–78	1.5–2σ	1 3%			2 7%		5 17%	19 66%	2 7%
39–58	1–1.5σ	7 10%			12 17%	1 1%	27 39%	19 28%	3 4%
>39	>1σ	8 6%			14 11%	1 1%	33 26%	64 51%	5 4%

important to note that both men and womam exhibited higher than average mortality rates when MT+ was present.

Table 4 illustrates that although MT+ was recorded on only 12.5% of summer days, on 51% (64/125) of those days the excess mortality exceeded one standard deviation above the average. Furthermore, MT+ was present on 96% (26/27) of the days that had mortality rates in excess of two standard deviations above the average. Clearly there is a strong relationship between MT+ and unusually high mortality rates in Shanghai.

Excess death algorithm

Typically the offensive air mass that contains the highest mortality, in this case MT+, also contains the highest standard deviation of mortality. Thus, it is important to discern which within-air-mass parameters on MT+ days are most closely linked to mortality. These parameters include meteorological factors such as maximum, minimum, and mean apparent temperature values (at 0200, 0800, 1400 and 2000 hours LST) for the current and previous days, the 1400 hour temperature and dew point temperature, the 0200 hour temperature, the mean daily cloud cover, and the sum of cooling degree hours for the day and the previous day. Several important non-meteorological factors were also evaluated, such as when in the season the offensive air mass occurred and the number of consecutive days the air mass was present.

The parameters that affected the variability of mortality within the offensive air mass were identified by stepwise linear regression, and the subsequent algorithm can be used to estimate excess mortality on days when weather emergencies are declared.

The excess death algorithm for an MT+ air mass was determined to be:

$$\mathrm{ED} = -430.8 + (15.65\mathrm{DIR}_5) + (11.71T_{\mathrm{av,app}})$$
$$(n = 174,\ S = 68,\ r = 0.51)$$

Table 5 Heat/health warnings in 1999: levels I–III

Date	Maximum temperature (°C)	Air mass	Predicted		Actual	
			Excess deaths	Level	Excess deaths	level
9 September 1999	34.9	MT+	49	I	45	I
10 September 1999	34.9	MT+	67	II	69	II
11 September 1999	35.2	MT+	85	III	85	III
12 September 1999	33.3	MT+	73	II	41	I
13 September 1999	30.8	MT+	57	II	54	II

Where ED is the number of excess deaths related to the heat wave, DIR_5 is the number of consecutive days of the offensive air mass (5 days in the case of DIR_5) and $T_{av,\,app}$ is the average apparent temperature at 0200, 0800, 1400 and 2000 hours.

The heat/health watch/warning system has been established on the basis of the identification of an offensive air mass that has been shown to be associated with elevated mortality rates in summer. Furthermore, an algorithm for excess deaths associated with this offensive air mass has been created for further guidance. Using Shanghai's limited local numerical weather forecast data for the days ahead, it is possible to predict the arrival of an offensive air mass up to 48 h before it arrives. If this procedure forecasts the arrival of an MT+ air mass 2 days in advance, the excess-death algorithm will be run to predict how human health might be compromised by the oncoming offensive air mass. Since not all offensive air mass days are associated with higher than average mortality rates, a heat-warning message will be issued only if the excess-death algorithm predicts elevated mortality. Depending upon the number of excess deaths predicted, the heat/health watch/warning system issues one of three levels of warning. A level I warning is issued if 40–59 deaths ($>1.0\sigma$ and $< 1.5\sigma$) are predicted, a level II warning is issued if 60–79 deaths ($>1.5\sigma$ and $<2.0\sigma$) are predicted, and level III warning is issued if 80 or more deaths ($>2.0\sigma$) are predicted. A series of interventions, such as media announcements (TV, radio stations, and the newspaper), health education, preparation of hospitals and public services, and ensuring the availability of water and power and of air-conditioned facilities, are initiated by the Shanghai Municipal Health Bureau along with other agencies.

System validation

In order to verify the predictive power of this heat/health system, the model was run throughout the summer of 1999. The summer proved to be relatively cool and only 1 day (11 September) had a maximum temperature that exceeded 35 °C. However, the system did detect several consecutive days of MT+ between 9 and 13 September. During this period, the algorithm predicted 331 excess deaths, only slightly more than the 294 excess deaths that were recorded (Table 5). The warm spell of 9–13 September successfully illustrated how the system's predictive power can help city officials determine when the public should be alerted to help prevent heat-related mortality.

Conclusion

There is little doubt that heat contributes to increased mortality levels, especially within urban areas, and it is our belief that an operational heat/health watch/warning system can be used to save lives and lessen the negative impact of heat waves. The watch/warning systems are based on a synoptic climatological procedure that identifies "high-risk" air masses that are historically associated with increased human mortality. Air mass occurrence can be predicted up to 48 h in advance with the use of model output statistics guidance forecast data. If a high-risk air mass is forecast, an algorithm has been developed that estimates the number of heat-related deaths expected in Shanghai. City health departments can, in turn, use this information to develop mitigation procedures in an attempt to reduce the risk of heat-related mortality. Running the model for the summer of 1999 suggests the algorithm is an adequate predictor of heat-related mortality, especially throughout a warm spell with several consecutive days of an oppressive air mass.

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